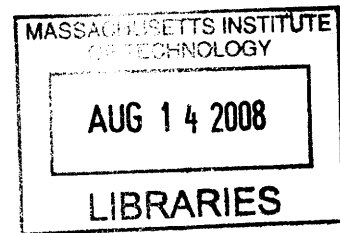


Power Requirements for a Rapid-Fire Projectile Toy Concept

by

Andrew Hurwich



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## **ABSTRACT**

The toy industry holds a large portion of the American consumer market, and new products are in constant demand. A new mechanism for use in children's toys has been proposed to fire small plastic balls at a rate of over four hundred per minute. A portable, small, and safe power system must be developed for this mechanism before it is implemented in new children's products. Power requirements for the device have been estimated based on safety guidelines to be 12 Watts. This rate is feasibly supplied by a manually-compressed pressurized air system similar to systems currently used in water-shooting children's toys. Such a system was incorporated into the new mechanism and subsequent tests confirmed this estimate. Test results demonstrated that the quality of air seals and the method of physically activating the mechanism are important areas of focus in next-level prototypes. This paper makes recommendations for improvements in these areas.

Thesis Supervisor: David Wallace

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# **Chapter 1**

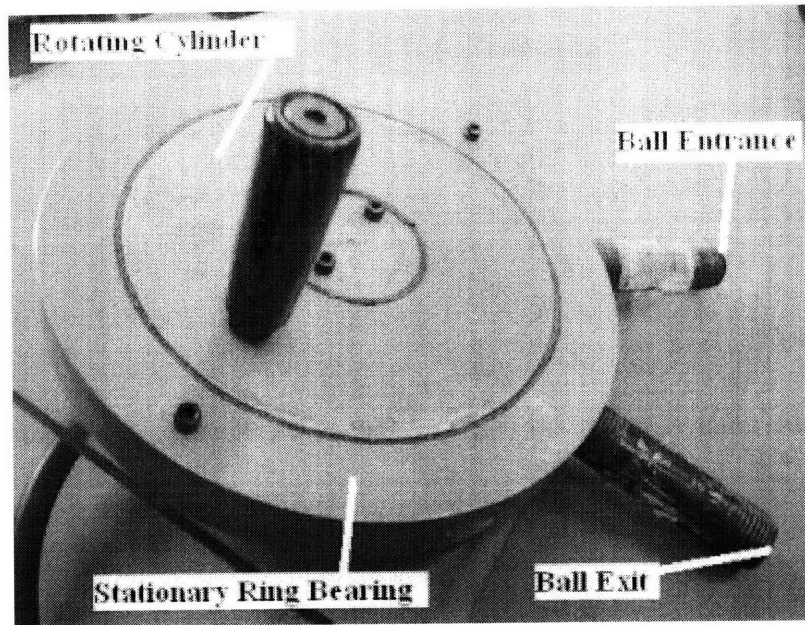
## **Introduction**

### **1.1 Objective**

The goal of this research was to further develop the design of a proposed projectile-toy concept. The concept prototype demonstrated the feasibility of a rapid ball-firing mechanism powered by compressed air from a compressed air cylinder. Because of their mass and potentially hazardous nature, compressed air cylinders are not appropriate for use in small children's toys. This research explored alternative methods for powering the mechanism in order to make it more suitable for implementation in children's projectile toys.

### **1.2 Background**

The toy industry holds a significant portion of the American consumer market. Because the demand for new toys is high, research and development of new mechanisms for toys is important. A novel system for shooting foam balls at a high rate of fire has been developed to a functional stage that is not yet ready for use in consumer toys because of its power requirements. The current mechanism is capable of firing small plastic balls at a rate of approximately four hundred per minute. It uses a manually rotated circular cylinder within a stationary ring bearing to synchronize ball loading and firing (see Figure 1).



**Figure 1: Existing prototype mechanism, showing ball entrance and exit, and rotating cylinder within stationary ring bearing.**

This prototype uses compressed air from a high-pressure air cylinder to fire the balls. However, because the air source is potentially hazardous as well as bulky and heavy, it is not easily portable and not suitable for use in children's toys. In order for the mechanism to be implemented in toys, a safer and more portable power supply must be found.

## Chapter 2

# Alternative Power Supply Exploration

### 2.1 System Power Requirements

The power consumption of the prototype is dependent on the desired kinetic energy of each ball fired and the rate of fire of the device. Because the prototype is meant for use in children's toys, the kinetic energy of the balls must be limited by safety concerns: the kinetic energy of each ball must be low enough so that it will not potentially cause injury if it strikes a young child. General safety guidelines were obtained from Hasbro Incorporated<sup>1</sup>, a toy company with a successful line of projectile children's toys. Their guidelines define *kinetic energy density* as the kinetic energy of a projectile divided by the area of a flat target the projectile contacts upon collision. Any projectile with a kinetic energy density of greater than  $1600 \text{ J/m}^2$  must be specially investigated to ensure its safety<sup>2</sup>; this value was taken as the maximum and desired kinetic energy density of the balls fired by the prototype. It was assumed that the impact area of the ball would be  $\frac{1}{4}$  its cross-sectional area. With this assumption and the value of the maximum kinetic energy density, the desired kinetic energy of each ball was calculated to be 0.6 Joules. At a firing rate of four hundred balls per minute, this equals 4 Watts dissipated through firing, assuming no losses.

### 2.2 Hand-Pumped Compressed Air

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<sup>1</sup> <http://www.hasbro.com/>

<sup>2</sup> B. Kudrowitz. "Exploration of Concepts for Projectile Toys" Massachusetts Institute of Technology, September 2005

Manually compressed air is a common power supply for toy water guns, and manually compressed air tanks are suitable for use in children's toys. If it were capable of supplying the needed power, its portability and recharge-ability would make a manually compressed air system would be ideal for powering the device in a projectile toy. There are two general types of manually compressed air systems used in current toys: unsupported systems that can be charged by pumping with one hand, and supported systems that must be rested against a sturdy surface and pumped with two hands. It is assumed that a child can provide 35 N force with the former system, and a 90 N force with the latter [citation needed]. A large reasonable stroke length for an air pump is 20 cm [citation needed]. By multiplying force supplied by stroke length, and assuming a pump efficiency of 30%, the maximum energy stored in one stroke for unsupported and supported systems are 2 J and 5 J, respectively. Therefore, for one second of firing under ideal operating conditions, a child would have to pump an unsupported air compression system twice and a supported one once. This would be an acceptable level of effort expended by the child for the amount of firing time gained.

## Chapter 3

### Feasibility Confirmation

#### 3.1 Test Apparatus

A sketch model was developed to confirm the feasibility of manually compressed air in powering the prototype. An existing toy water gun with a 6 L supported-pumping-style air tank was purchased from a local toy store, and the air tank was connected to the prototype. A pressure gauge was installed between the tank and prototype to measure the pressure in the system. The prototype bearing surface was cleaned and lubricated with Vaseline jelly, and the prototype was clamped to a lab bench-top. Delrin bearings were clamped over the rotating inner ring to prevent it from rocking within the bearing, which would otherwise cause it to jam (see Figure 2).

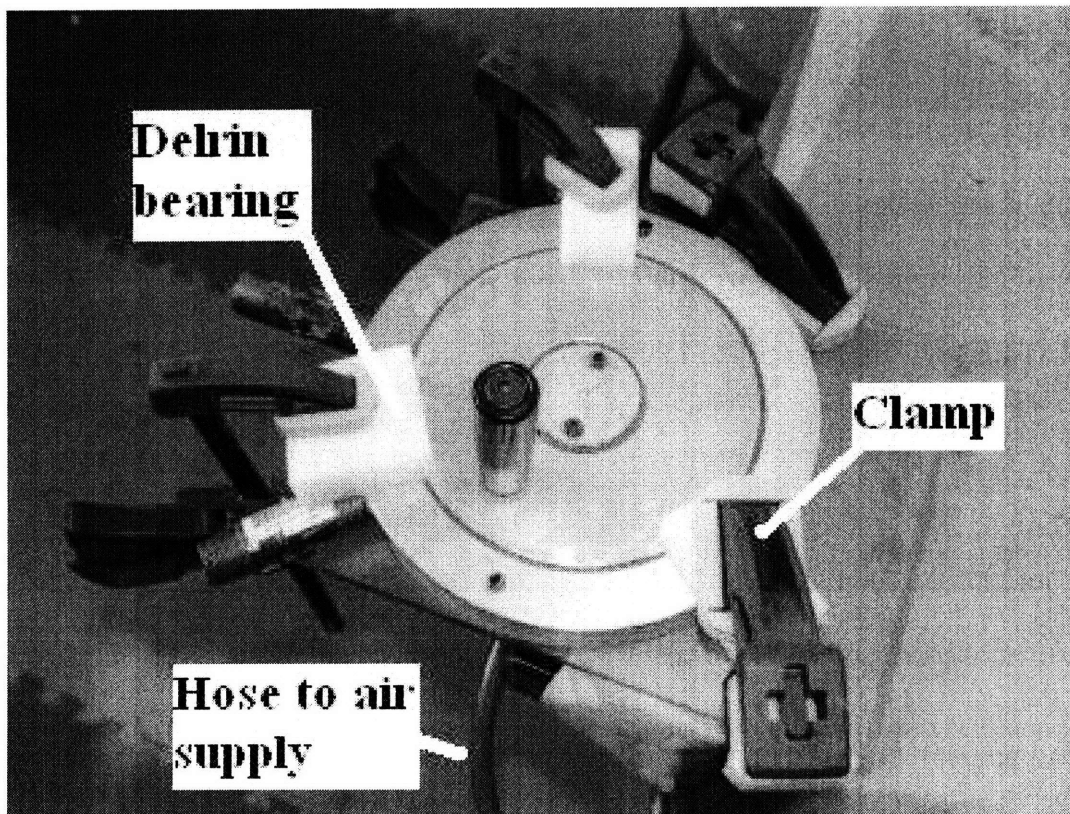


Figure 2: Prototype mechanism clamped for testing with delrin bearings in place.

The air tank was then pressurized according to the tank manufacturer instructions, and multiple firing tests were carried out.

### **3.2 Testing Procedures and Results**

The air tank selected was capable of being pressurized to 20 psi in 25 pumps. Further pumps were capable of raising the internal pressure to 25 psi, but leakage inherent in the tank prevented any higher pressures. With the initial setup of the air tank connected directly to the prototype, the air pumped into the tank was immediately released through the bearing in the prototype, which was not designed to be air-tight. A clamp was put over the tubing between the air tank and prototype to act as a valve. This allowed the tank pressure to build without leaking out of the bearing.

In the second test attempts, the clamp was applied and the tank was pressurized to 20 psi. Balls were loaded into the prototype, and the clamp was released. With this test procedure, the air from the tank still leaked out of the bearing before the inner ring could be rotated to fire the balls. The majority of the air leaked out within 1 second of the clamp being released. Adding more Vaseline jelly to the bearing did not create an adequate air-tight seal to correct this problem, although it did succeed in occluding the firing pathways, preventing the balls from moving freely within the prototype as they otherwise should have.

For the third test attempts, the system was cleaned of excess lubricant and prepared in the same manner as previously. However, in these attempts, the inner ring was rotated continuously by one experimenter before the clamp was released. A second experimenter then released the clamp, allowing air to flow from the tank to the prototype.

Because the inner ring was being rotated when the clamp was released, significant volumes of air passed through the prototype as designed, firing several balls. The air supply in these tests, like that of the previous tests, was exhausted within 1 second. After practicing the test procedure, the experimenters were able to consistently fire four or five balls before the air supply ran out with each test.

## **Chapter 4**

### **Design Recommendations**

#### **4.1 Air Tank Design**

The air tank used in this testing was capable of reaching pressures not greater than 25 psi. A higher pressure will allow for a larger mass of air to be stored in the same volume, or a smaller tank to hold a given air mass. As a general safety guideline, 40 psi is the maximum pressure that a typical plastic tank on a children's toy should hold—this is the pressure the final air tank should be designed to reach. The air pump should be capable of producing these pressures, at which it should require 35 N to actuate. The air pump stroke length should be 0.2 m. To ensure the user is maintaining pressure in the tank adequate for firing, a pressure gauge should be installed on the toy in a readily visible place, with indicators telling the users when the tank is at adequate pressure, when it is close to needed recharging, and when it needs recharging.

#### **4.2 Overall Air Tightness**

The air leak encountered in the first series of tests shows the need for much refinement in the prototype's design. The final version of the mechanism must be sufficiently air-tight so only insignificant volumes of air leak from the system during firing. Otherwise, excessive pumping will be required from the user, potentially decreasing enjoyment through user fatigue and play time lost during pumping. The design of the bearing that houses the rotating ring will be a significant factor in determining air-tightness. The height of the bearing in the current prototype is small, and provides little resistance to the flow of compressed air through its surfaces. A taller bearing would provide more



resistance, lowering the volume flow rate of air passing through the bearing, decreasing the total volume of air lost during any given firing interval.

Enclosing the firing ring on more dimensions will also decrease the air leaked from the system. The current prototype has an entire face open to the atmosphere to allow the user to rotate the firing ring. Covering this face partially, especially along the bearing, would increase the flow resistance of the escaping air, further decreasing the volume lost during firing. A possible extension of this idea would be to encapsulate the firing mechanism completely within an air-tight shell, with openings in the shell for only the air supply, ball feeding, ball firing, and bearings for the rotating firing ring (see Figure 3).

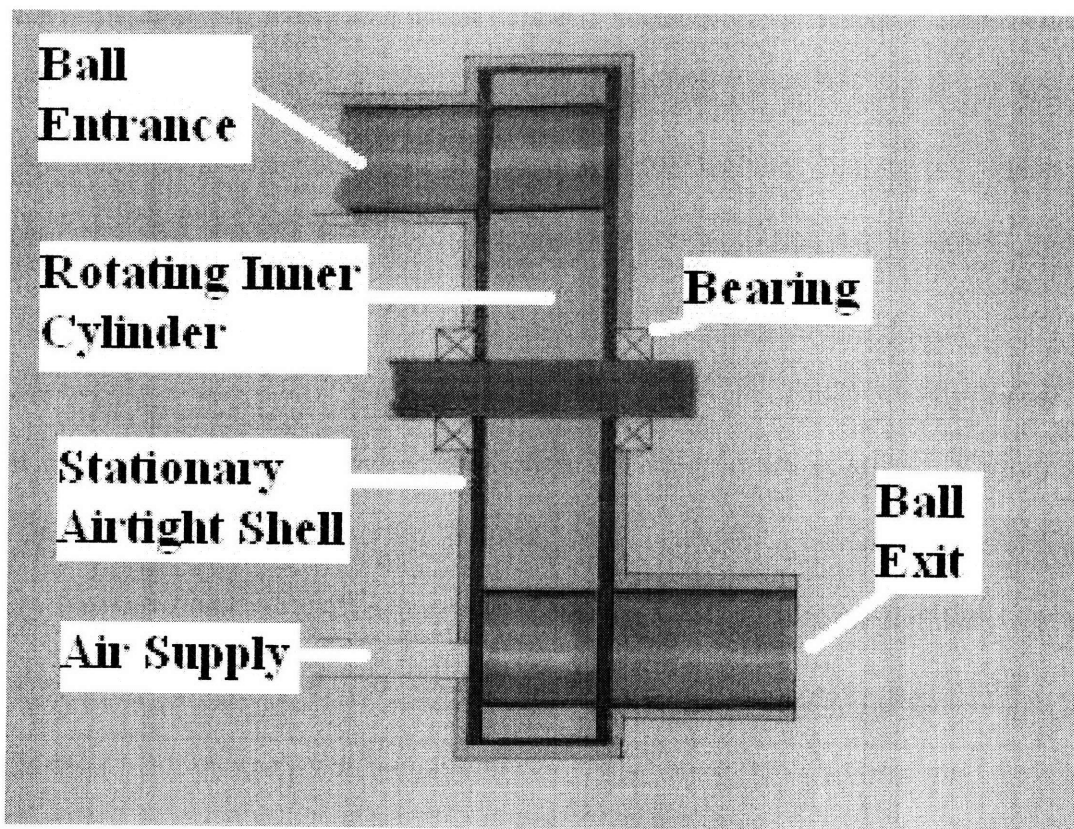


Figure 3: Cross-section of a possible firing mechanism and airtight shell, showing locations of the breaches in the shell and the rotating cylinder.

This would reduce the avenues for air to escape to the ball feeding and firing holes, and the bearing holes. Air flow through the bearing holes can be reduced by using sealed bearings, which are commercially available. Air loss through the ball feeding hole can be eliminated if the ball hopper is made air tight and pressurized by connection to the air tank. This would leave the ball firing hole as the only possible source of significant air loss, which can be minimized by appropriate seals around the hole.

### **4.3 Actuating the Firing Ring**

The tests performed with the prototype required two people to perform: one to turn the firing ring, and another to open the clamp-valve to allow the air to flow. To enable one person to operate a final version of the firing mechanism alone, it is recommended that the firing ring be powered by a motor that the operator can control. This will remove much of the manual labor of the firing process and make for a more enjoyable user experience. A possible method of control of both the motor and valve would be the implementation of a dual trigger. When pulled half-way, the motor would be activated and the firing ring would spin. This would prepare the firing mechanism, like in the successful prototype tests, for the flow of pressurized air, which could be released by fully pulling the trigger. With this method, the user could operate the firing mechanism with one or two fingers as on a typical projectile toy, while holding and aiming the toy with the remaining hands.

Electrically actuating the firing ring creates the challenge of powering the actuator. Batteries installed in the handle or other convenient place in the toy would be adequate for powering many small motors. However, the motor would have to be capable of spinning the firing ring against the friction created by the air seals in the firing

mechanism. A balance will have to be established between the need for creating an excellent seal so air volume loss is not significant and the need to have a manageably sized motor that won't consume excess amounts of power. Further testing should be performed to determine the ideal size and material of sealants based on the constraint that they shouldn't create large frictional forces that a small motor driving the firing ring could not overcome.

## **Chapter 5**

### **Conclusion**

The tested manually-compressed pressurized-air system was shown to be a feasible method for powering the plastic ball rapid-fire prototype. The system's portability and prior successful use in other existing children's toys make it an obvious choice for use with this one. The design features suggested in this paper should make the power system better capable of supplying the necessary power to operate the firing mechanism, allowing its further development into a final product.